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Energy and economic performance of rooftop PV panels in the hot and dry climate of Iran

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ABSTRACT

Photovoltaic (PV) Panels, one of the more promising renewable energy technologies, are growing rapidly nowadays, especially in developed countries. However, these systems have not achieved public acceptance in some countries due to low energy efficiency and poor economic performance, especially in countries which are subsidized in energy tariffs. In this paper, the energy and economic performance of fourteen rooftop PV systems with the power of 5 kW in the hot and dry climate of Iran are assessed by monitoring the total annual energy production and simulation. The monitored data is used to analyze systems' economic performance via Pay-Back Period (PBP), Net Present Value (NPV), Return of Investment (ROI) and Levelized Cost of Energy (LCOE). Results show that single array configuration systems have the maximum energy production while dividing the system decreases the production. Economic analysis shows that the average PBP is 11.6 years under actual price of electricity (0.21$), however it is 46.9–50.5 years under subsidized average tariffs. ROI values range from 2.6 to 3.2 with the average of 2.9 for actual prices. Under subsidized prices, the cash generated by investment cannot even offset the costs that the investment requires during its lifetime with NCF and NPV being both negative. Overall, the systems are not economically beneficial under subsidized average tariffs in Iran, which discourages private and public sectors to investment on these systems. Environmentally, each PV system can averagely reduce 500 kg CO_2 emission in the first year of installation and fourteen of them can approximately reduce 1,613,900 kg of CO_2 emission during life time of PV panels.

1. Introduction

The world's dependence upon fossil fuels for its energy needs results in high CO_2 emissions. Building industry accounts for approximately one third of global energy use and one fifth of global greenhouse gas emissions (IEA, 2016). By using renewable energy sources (e.g. solar, wind, etc.) for generating electricity, which is ranked second among world's total final energy consumption, considerable amount of greenhouse gas (GHG) emission can be reduced (Adam and Apaydin, 2016; Coughlin and Kandt, 2011). Although a large amount of GHG is released during manufacturing of PV panels (Al-Salaymeh et al., 2010; Kim et al., 2014), generated electricity reduces emissions by at least 89% compared to grid electricity (Kannan et al., 2006); convectional grid electricity sources use much primary energy in the process of production, transmitting and distribution (Fthenakis et al., 2008).

Iran is ranked 30th among countries with the highest electricity energy consumption; the total electricity energy consumed is 186 Terawatt-hour (TWh), with 8–9% increase per year. Due to government's subsidies, electricity price is much lower in Iran than that in most of the world countries, while Iran is ranked second among OPEC with a potential to export natural gas to Europe and Asia. The electricity is mainly generated by fossil fuels (94%), about 6% by hydro, and less than 1% by renewable energy resources (Abbaspour and Hennicke, 2005; Moshiri, 2013; Kazemi and Zahedi, 2002). To address environmental issues and to increase gas export applying renewable energy seems necessary in Iran (G. German Solar Association and BSW-Solar,Berlin, 2016).

Photovoltaics are known as a common renewable electricity generation system. Iran has a great potential for solar radiation; more than 300 clear sunny days a year on two third of the land, and the average solar radiation of 19.23 MJ/m^2 and 2800 radiation hours per year (Kazemi and Zahedi, 2002). Horizontal radiation at

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Abbreviations and nomenclature

PBP	Pay-Back Period
NPV	Net Present Value
NCF	Net Cash Flow
ROI	Return of Investment
LCOE	Levelized Cost of Energy
GHG	greenhouse gas
TWh	Terawatt-hour
FIT	Feed-in Tariffs
LCOE	Levelized cost of electricity
PR	Performance Ratio
PAE	Percentage of Annual Electricity
CED	Carbon dioxide Emission Reduction
PV	Photovoltaic
NOCT	Nominal Operating Cell Temperature
P_s	total output measured energy (kWh)
I	Irradiance (kWh/m^2)
A	area of array (m^2)
E_s	efficiency of the panel
C_0	initial investment cost
Ct	net cash inflow during the period t
N_y	Life time
i	discount rate
O&M	operations and maintenance

some stations were recorded averagely higher than 500 W/m^2 in a year (Alamdari et al., 2012) which is economically viable for photovoltaic panels (El Chaar and Lamont, 2010), Fig. 1. Despite the high potential of solar power and serious need of new energy sources in near future, current economic situation and policies do not make PV systems popular in Iran. In addition to solar plants which belong to governmental energy producers, rooftop PV panels can be beneficial in local private sectors without any land use problems. In other words, spacious useless flat roof areas and considerable energy budgets in public services, governmental and semi-public buildings provide a good potential to use PVs as an economically beneficial approach.

Different aspects of photovoltaics have been the target of research in recent years, e.g., energy performance, economic performance, PV cell characteristics and Carbon footprints. However, it is uncertain to only consider financial aspects of installing PV systems (Orioli and Di Gangi, 2014). The economic performance of the energy generation is known as a determining factor in the development of these systems (Kandt, 2011; Rose et al., 2016), especially in countries with highly subsidized energy tariffs. A clear understanding of the relative cost-effectiveness and feasibility of different energy technologies is paramount in determining energy management policies for any nation (Esen and Yuksel, 2013; Esen et al., 2017; Branker et al., 2011). Economic performance assessment methods have been introduced and defined in different studies (El Chaar and Lamont, 2010; Rose et al., 2016; Esen et al., 2006, 2007; Pillai et al., 2014). On the economic convenience of PV panels for private investors in Iran, the study by Abbaspour and Hennicke (2005) shows that they are not profitable even if 50 percent of the investments is subsidized (Abbaspour and Hennicke, 2005). Although the demand and incentives for renewable energy have been increasing (Branker et al., 2011) and the cost of PV systems has been reducing over the years (Coughlin and Kandt, 2011; Feldman et al., 2012; Curthoys, 2012), several studies show that the high initial costs of PV systems compared to the cost of fossil fuel electricity are still a deterrent for most consumers (Hsu, 2012; Ren et al., 2009). Furthermore, researches state that payback period is significantly influenced by efficiency, local price of electricity, and most importantly, capital cost (Ren et al., 2009). In order to increase customer's benefits, increasing grid electricity price, reducing PV systems' prices, and increasing inverter lifetime are required (Coughlin and Kandt, 2011; (Branker et al., 2011). Studies imply that Feed-in Tariffs (FIT) (Bernal-Agustín and Dufo-López, 2006; Hestnes, 1999), grants, and capital subsidies (Hsu, 2012) are also incentives for public and private sectors to install PV systems. The economic feasibility of PV projects is increasingly being evaluated using the levelized cost of electricity (LCOE) generation. Photovoltaics LCOE is reported from 0.12 to 0.78 $/kWh in different countries (Branker et al., 2011; Quansah and Adaramola, 2016).

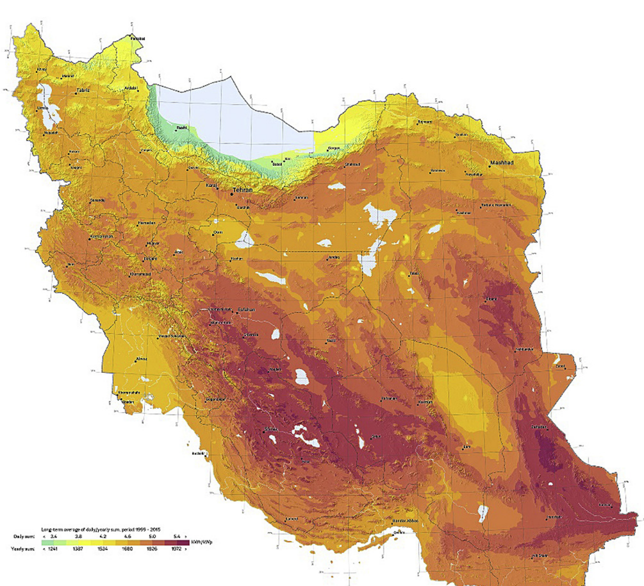

Fig. 1. Photovoltaic power potential in Iran (Retrieved from solargis, 2015).

The commercial demand has led into the development of many PV analysis and planning software packages to predict the performance of grid connected photovoltaic (PV) system i.e., PVSYST, RETScreen, TRNSYS, PVSOL (Accuracy analysis of software for the estimation and planning of photovoltaic installations, 2014). Modol et al., used TRANSYS to model a grid connected PV system and compared the results with measured data (Quansah and Adaramola, 2016). Axaopoulos et al., studied the calculative accuracy of a few PV simulation softwares in comparison to the real electrical energy generated by a grid-connected 19.8 kW photovoltaic installation. Results displayed that the software packages tend to overestimate the global irradiation received by the PV modules but still significantly underestimate the electrical energy generated by the installation (Accuracy analysis of software for the estimation and planning of photovoltaic installations, 2014).

The objective of this study is to evaluate electricity generation, CO2 production, and economic performance of rooftop PV panels. To carry out the study, one-year monitored data of fourteen rooftop PV systems with the power of 5 kW on educational buildings was analyzed. Performance parameters calculated include: Performance Ratio (PR), Percentage of Annual Electricity (PAE), Carbon dioxide Emission Reduction (CED), Net Present Value (NPV),

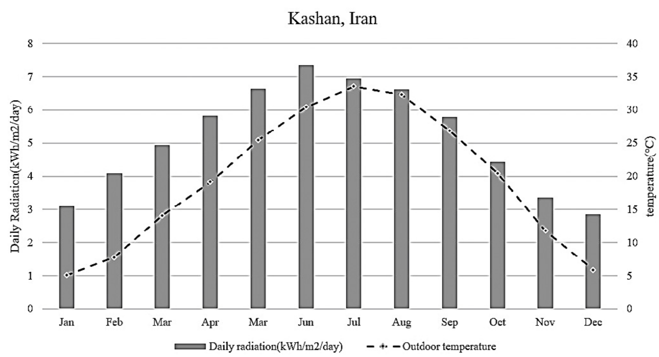

Fig. 2. Monthly horizontal solar radiation and average air temperature in Kashan.

Payback period (PBP), Return of Investment (ROI) and Levelized Cost of Electricity (LCOE). To provide reliable data for design and installation of PV panels, energy performance of studied PV systems has been modeled and compared to field results.

2. Methodology

2.1. Case studies

Rooftop PV panels in public schools in Kashan, Iran have been selected for this study to evaluate their economic and environmental performance. Kashan (33° 58′ 59” N/51° 25′ 56” E) climate is classified as BWh by the Köppen-Geiger system, with hot and dry climate and virtually no rainfall during the year. According to Kashan Weather Station, the sky of Kashan is 67% clear, 24% partly cloudy and 9% cloudy during a year (Chaharmahal Weather Station Website). Monthly horizontal solar radiation and average temperature in Kashan are shown in Fig. 2 (Irradiation data for every place on Earth). In 2014, the government funded solar PV projects in educational buildings all over the country, including 14 schools in Kashan. All schools are located within a 5-km radius from the city center, surrounded by urban buildings with the same average height and are occupied from 8:00 a.m. to 1:00 p.m., October to June. Electrical loads are mainly contributed to lighting systems; however, cooling systems account for most of the electrical load in May and June.

The methodology in this assessment contains 4 steps which are illustrated in methodology flowchart in Fig. 3: 1) Monitoring PV panels' power generation during a year 2) Simulating electricity generation 3. Energy and environment analysis and 4) Economic analysis.

2.2. Monitoring

Multi-crystalline silicon Panels, the most common available in the market, are used in these schools, described in Table 1. 5 kW PV panels are mounted on unshaded roofs at an angle equal to Kashan Latitude (33°) to have an efficient production in both summer and winter (Fig. 4).

A Sunny Tripower 15000 TL inverter, a SMA Sunny SensorBox with integrated solar radiation sensor and an external temperature sensor module were used to collect environmental data from PV systems on an hourly basis, which were then used for monitoring energy performance in each case. The solar irradiation sensors have been calibrated with the help of TES 1333R solar power meter. A DataQ- DI-245 data acquisitions system has been used to collect and process the data from the sensors and inverter. Data are averaged daily using the application program of the data acquisition system.

Total produced energy has been recorded from August 2014 for a year, Table 2. Annual electricity consumption of each school is obtained from electricity bills. Total energy generation, initial cost, unit panel cost and the percentage of the electricity consumption that is generated by PV systems are reported in Table 2 for each school. Low electricity generation in Iran and high energy demand of buildings and industries on the other hand, make it logical to produce electricity and sell it back to the local grid. Moreover, in case of educational buildings, the total generated electricity is sold

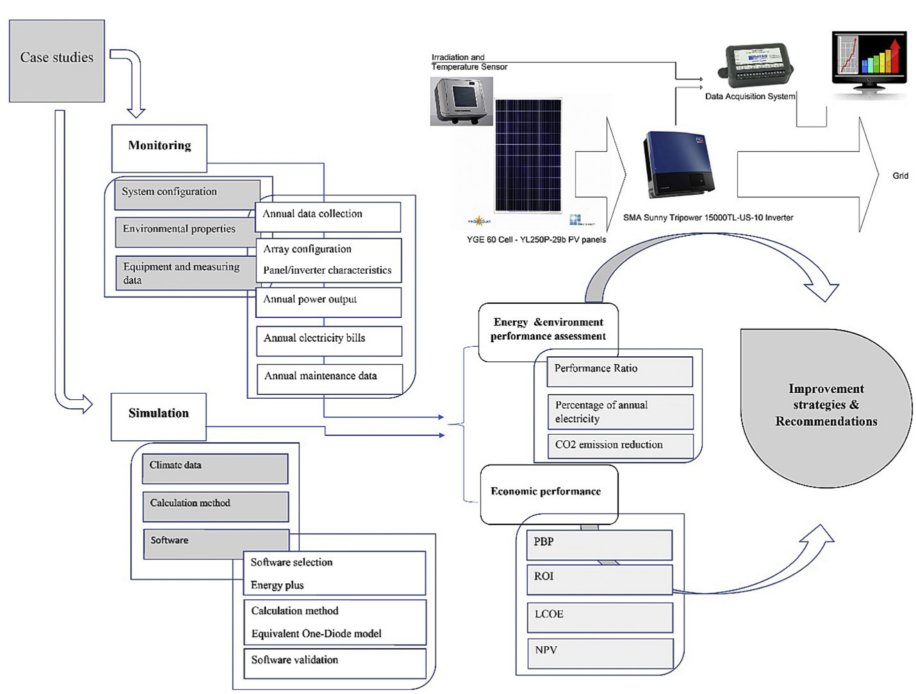

Fig. 3. Research Methodology flowchart.

Table 1
Station identification and solar panel characteristics.

Station Identification		Solar Panel Characteristics			
Continent	Asia	Panels' capacity (w)	250	Short circuit current (A)	8/79
Country	Iran	Panels' Type	YL250P-29b	Max system voltage (V)	1000
Province	Isfahan	Related Max Power (w)	250 (~0 + 5)	Rated efficiency (%)	13.65
City	Kashan	Related Voltage (V)	30/4	Deterioration rate (%)	0.7
Latitude	33.98°	Related Current (A)	8/24	Project lifetime	25
Longitude	51.40°	Max Series Fuse (A)	15	Test Conditions	AM 1/5, 25 °C, 1000 w/m^2
Elevation	946.37 M	Open circuit voltage (V)	38/4	Invertors	5 kW SMA Germany

to the utility grid because of high guaranteed purchase in PV development plan policies (21 cent) and the subsidized educational building electricity tariffs (0.3–1.1 cent).

2.3. Simulation

PV simulations are carried out for different designs from standalone, off grid system to grid connected building integrated photovoltaics by professional photovoltaic system design software (e.g., RETScreen, PVSYST PV*SOL Expert, PolySun and HOMER) and also whole building dynamic energy simulation software (e.g., TRNSYS and EnergyPlus). For the purpose of this research, annual power generation of the rooftop panels have been modeled by two tools: Energyplus, a whole building energy simulation program that engineers, architects, and researchers use to model energy consumption and generation in buildings. In order to assess the accuracy of results, PV*SOL is also used to predict annual energy production of the used panels. PV*SOL computes average frequency of the modules shadowed by the objects and shows the results graphically, helping users to optimize panel allocation depending on shading position.

Both tools use the same method for predicting electricity generated by photovoltaic panels. The equivalent one-diode method uses empirical relationships to more accurately predict PV operating performance based on dynamic parameters, such as incident radiation and cell temperature (Griffith and Ellis, 2004). This model is also known as the four or five parameters TRNSYS model. The four-parameter equivalent circuit is shown in Fig. 5. V is the load voltage and I is the current flowing through the load and PV. The “four parameters” in the model are $I_{L\ ref}$ (Module photocurrent at reference conditions), $I_{D\ ref}$ (Diode reverse saturation current at reference conditions), g (Module shunt resistance) and R_s (Module series resistance). These are empirical values that cannot be determined directly through physical measurement. Both software calculates these values from manufactures' catalog data i.e., short circuit current, open circuit voltage, voltage at maximum power, current at maximum power, temperature coefficient of short circuit current, temperature coefficient of open circuit voltage, number of cells in series per module, cell temperature at NOCT (Nominal Operating Cell Temperature) condition, and module area (U.S. Department of Energy, 2012). This model is applied and validated in many studies, reporting 5–8% error when comparing predicted energy generation to the actual data (Accuracy analysis of software for the estimation and planning of photovoltaic installations, 2014). In order to decrease simulation errors, monthly global irradiation on the horizontal plane and ambient temperature recorded during monitoring period were used in both software.

3. Results

3.1. Energy performance

Monitored and simulated electricity generation of PV systems are presented in Fig. 6. Although all used PV systems have a capacity of 5 kW, outputs differ modestly based on the arrangement, Table 2 and Fig. 6. Those arranged in 1 × 20 perform better than those in 2 × 10 or 4 × 5 arrays. The arrangements differ significantly in different schools with regards to their roof shape and size. Generally, 5 kW systems arranged 1 × 20 are more efficient as they generate more energy and have lower initial cost (lower costs of installation and wiring). The difference between maximum and minimum generated electricity is 12.2%, with the maximum of 9428 kWh per year for 1 × 20 and minimum of 8267 kWh for 10 × 5 × 5, Table 2.

As atmospheric conditions also affect system performance, irradiation and maximum temperature of the panels were logged daily. Fig. 7 shows averaged annual temperature and irradiation of

Fig. 4. Some of the case studies, various arrangements in different cases (1: 5-10-5; 2:1 × 20; 3,4:2 × 10; 5:5 × 4; 6:4 × 5).

Table 2
Monitored data of 14 rooftop PV systems installed in Kashan.

Pro No.	Arrangement	System Capacity Potential (kW)	Total Energy Produced (kWh), Array output	Initial Capital Cost ($ per capacity), Purchase and Installation	Cost Per Unit ($/kW)	Annual Revenue (Income, $)	Annual Electricity (kWh) (Current Usage)	Percent of Annual electricity	Performance Ratio (%)
1	10, 5, 5	5	8276	14,683	2937	1958	11,544	75%	64%
2	10, 5, 5	5	8349	14,678	2936	1975	9916	90%	64%
3	10, 10	5	8389	14,660	2932	1985	23,075	40%	65%
4	10, 5, 5	5	8758	14,674	2935	2072	16,292	59%	68%
5	10, 10	5	8452	14,662	2932	2000	16,650	55%	65%
6	4, 4, 4, 4, 4	5	8550	14,700	2940	2023	14,517	58%	66%
7	5, 5, 5, 5	5	8569	14,680	2936	2027	51,260	18%	66%
8	15, 5	5	8827	14,648	2930	2088	24,560	39%	68%
9	10, 10	5	8878	14,652	2930	2101	17,409	51%	68%
10	10, 10	5	8949	14,665	2933	2117	5085	186%	69%
11	20	5	9267	14,069	2814	2193	2172	34%	71%
12	20	5	8851	14,632	2926	2094	24,566	38%	68%
13	20	5	9287	14,632	2926	2197	36,640	25%	72%
14	20	5	9400	14,632	2926	2224	8280	125%	72%

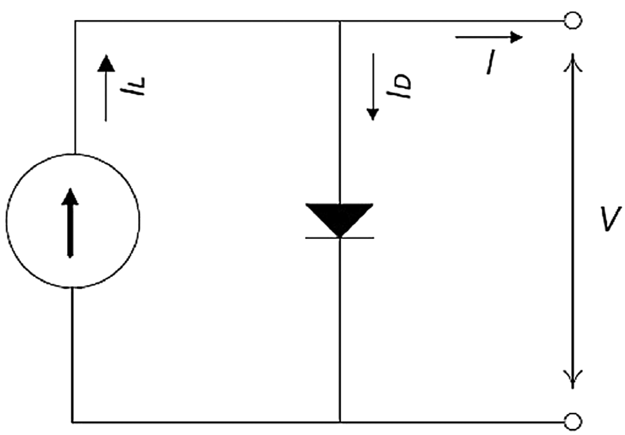

Fig. 5. Equivalent circuit in the four-parameter model (U.S. Department of Energy, 2012).

the panels. According to the results, temperature and irradiation of panels even with the same arrangements are different, in which the maximum amount of panel temperature recorded in case 12 and the maximum amount of irradiation on the panel occurred in case 14. The simultaneous effect of panel temperature and configuration on electricity generation is about 3.81%, while the effect of different irradiation in addition to the effect of panel configuration calculated about 5.29%, in comparison to the overall energy generation

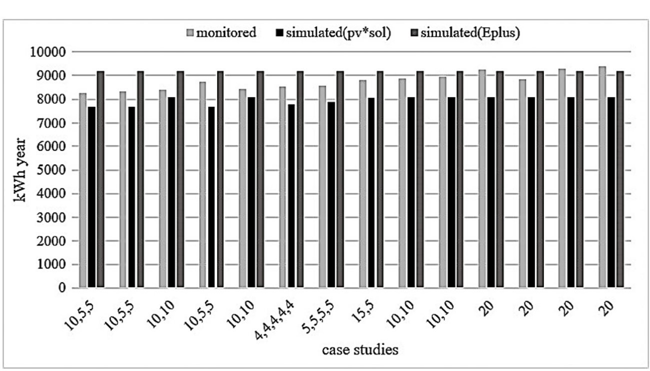

Fig. 6. Measured and simulated energy generation of PV systems with different arrays.

differs 12.2%, as above mentioned. However, this difference is less than 10% in panels with the same arrangements.

Results of EnergyPlus simulation are not different for various PV arrangements and are constant in all cases, Fig. 6. Simulated generated electricity equals to 9178 kWh which is about 97.3% of the abovementioned maximum generated electricity and 110.8% of the minimum, respectively. Minimum and maximum difference between monitored and simulated results is observed in 1×20 and $10 \times 5 \times 5$ configurations, which equals to 2.65% underestimation and 10.89% overestimation, respectively, Fig. 6. All four cases with 1×20 configurations have generated more energy than what expected by simulations which is due to their configurations. However, PV*SOL results differ by configuration, i.e., 1×20 module generate maximum energy and $10 \times 5 \times 5$ module produce minimum energy. The difference between monitored and simulated energy production equals to 3–13% with the average of 9%, in line with previous studies (Accuracy analysis of software for the estimation and planning of photovoltaic installations, 2014). While EnergyPlus mostly overestimates produced energy, PV*SOL underestimates electricity energy generation. Apart from factors like cabling, maintenance, inverters' loss, etc. that increase deviation in simulation results, different shading hours, due to different arrangements, is another main factor which causes discrepancies.

"Percent of Annual electricity" in Table 2 shows a large difference between produced electricity and current usage of the school in some cases, for instance case 2. Case studies are all one to three story schools, with large unshaded flat roofs on which more number of PV panels could be installed. Percent of Annual electricity could be greater for most cases if higher number of PV panels were installed.

The performance ratio is a measure of the quality of a PV plant that is independent of location and is therefore often described as a quality factor. The performance ratio (PR) is stated as percent and describes the relationship between the actual and theoretical energy outputs of the PV plant (SMA Solar Technology AG, 2015). The closer PR value is to 100% for a PV plant, the more efficient it is operating. The performance ratio (PR) is calculated for each case using eq (1). P_s is the total output measured energy (kWh), I is Irradiance (kWh/m^2), A is the area of array (m^2) and E_s is the efficiency of the panel.

$$PR = \frac{P_s}{(I{*}A{*}E_s){*}100} \quad (1)$$

PR ranges from 64 to 72% in different studied cases, with the highest value for the 1×20 arrangement. Thermal losses due to

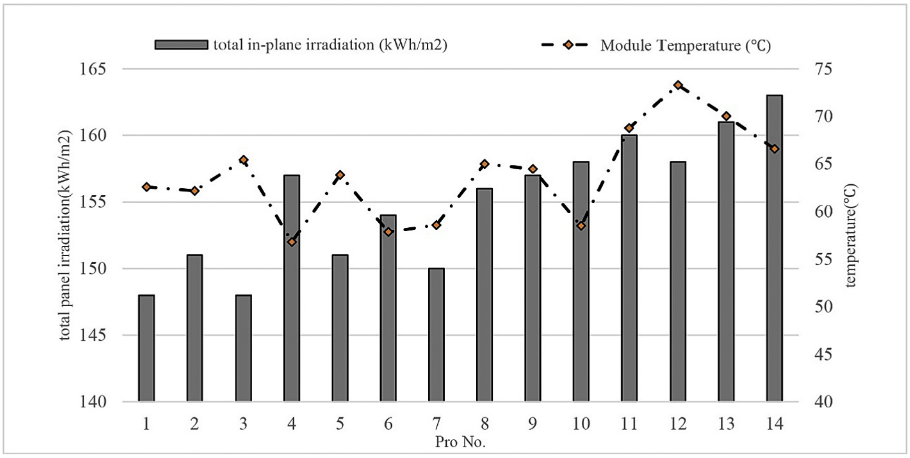

Fig. 7. Annual total panel irradiation and maximum module temperature in different cases.

solar panel heating, especially in summer is the main reason for the low performance ratio.

3.2. Environmental performance

Since electricity generated by PV systems don't require fossil fuels, its CO_2 emission is much lower. The environmental benefits of PV panels and their effect on CO_2 emission has been studied by many researchers (Quansah and Adaramola, 2016; U.S. Department of Energy, 2012; Freeman et al., 2014; Fu et al., 2015; Cucchiella et al., 2015). According to the study by Noorpoor and Kudahi (2015), average specific CO_2 emission factor is estimated to be 571.29 g/kWh in Iran (Noorpoor and Kudahi, 2015). Considering this factor, CO_2 emission reduction has been calculated for each school at the end of 25 years (Fig. 8). Each PV system can averagely reduce 500 kg CO_2 emission in the first year of installation in each school. During life time of PV panels, these 14 schools can approximately reduce 1,613,900 kg of CO_2 emission.

3.3. Economic performance

The economic performance of the PV systems is evaluated by four parameters; Net Present Value, Payback period, Return of investment and Levelized cost of energy. Electricity per unit costs of the panels in actual and subsidized tariffs are investigated by considering the following issues:

- Electricity production of each PV system is extrapolated using field measurement data from August 2014 to August 2015, and the annual deterioration rate of 0.7% which is assumed to be constant, Table 3.
- Annual management and maintenance costs are 0.1% of the investment cost. The maintenance and service costs increase by 2% each year (Abbaspour and Hennicke, 2005).
- Replacement of equipment (1% of the PV panels annually, invertors every five years), considering annual decreasing rate of equipment costs (11% incorporated to the 2014 cost).
- The cost of producing 1 kWh electricity is presumed to be fixed during 25 years (around 0.21$).
- 6.6% increase in annual school electricity price by considering the rate of energy price over the last 15 years, Fig. 9.

Economic performance of PV systems under actual electricity per unit costs without subsidies shows that payback periods range from 10.5 to 12.3 years with the average of 11.6 years for a 5 kW system, meaning that it takes 11.6 years to offset the initial costs, Table 3. ROI values (eq. (2)) range from 2.6 to 3.2, with the average of 2.9 for a 5 kW system, suggesting that the system provides

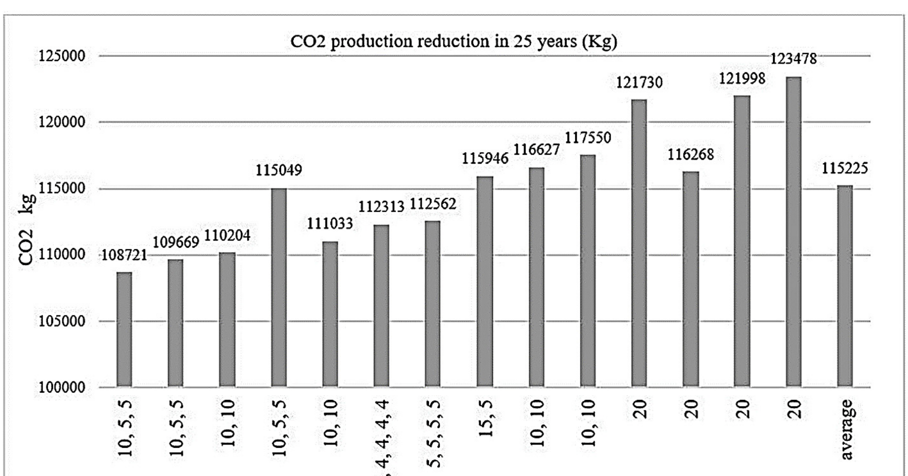

Fig. 8. Reduction in CO2 emission (Kg) at the end of 25 years.

Table 3
Shows economic performance of PV panels under actual electricity per unit costs and under subsidized average tariffs.

Pro No.	Actual or Subsidized	Initial Capital Cost ($)	Estimated Total Electricity Generated in 25 Y (kWh)	Cost Investment Requires	Cash Generated by investment in 25 Y($)	NCF	NPV	PBP	ROI
1	Actual	14,652	204,251	5769	48,325	42,556	27,904	11.5	2.9
	Subsidized				4528	−1241	−15893	48.0	−0.08
2	Actual	14,069	213,187	5752	50,440	44,688	30,619	10.5	3.2
	Subsidized				4726	−1026	−15095	46.9	−0.07
3	Actual	14,683	190,404	5770	45,049	39,279	24,596	12.4	2.7
	Subsidized				4221	−1549	−16232	49.2	−0.11
4	Actual	14,632	203,621	5769	48,176	42,407	27,775	11.5	2.9
	Subsidized				4514	−1255	−15887	48.2	−0.09
5	Actual	14,648	203,058	5769	48,043	42,274	27,626	11.6	2.9
	Subsidized				4501	−1268	−15916	48.2	−0.09
6	Actual	14,660	193,001	5770	45,664	39,894	25,234	12.1	2.7
	Subsidized				4279	−1491	−16151	49.1	−0.10
7	Actual	14,700	196,696	5771	46,538	40,767	26,067	12	2.8
	Subsidized				4360	−1411	−16111	49.2	−0.10
8	Actual	14,674	201,486	5770	47,671	41,901	27,227	11.7	2.9
	Subsidized				4467	−1303	−15977	47.8	−0.09
9	Actual	14,632	213,657	5769	50,551	44,782	30,150	11	3.1
	Subsidized				4736	−1033	−15665	47.3	−0.07
10	Actual	14,680	197,131	5770	46,641	40,871	26,191	11.9	2.8
	Subsidized				4370	−1400	−16080	48.7	−0.10
11	Actual	14,665	205,867	5770	48,708	42,938	28,273	11.4	2.9
	Subsidized				4564	−1206	−15871	47.9	−0.08
12	Actual	14,678	192,065	5770	45,442	39,672	24,994	12.2	2.7
	Subsidized				4258	−1512	−16190	49.2	−0.10
13	Actual	14,662	194,453	5770	46,007	40,237	25,575	12.1	2.7
	Subsidized				4311	−1459	−16121	48.9	−0.10
14	Actual	14,632	216,248	5769	51,164	45,395	30,763	10.8	3.1
	Subsidized				4794	–975	−15607	47.1	−0.07

around three times more savings than the initial capital cost. Although the systems do not have a large capacity, the results show economic convenience of PV panels under actual electricity per unit costs.

ROI = (Gain from investment − Cost of investment)/Cost of investment (2)

Payback periods range from 46.9 to 50.5 years under subsidized average tariffs, around twice the lifetime of PV panels. ROI values range from −0.07 t^0 -0.22 years, suggesting that the initial capital costs are 4.6–15 times higher than systems' savings. The cash generated by investment cannot even offset the costs that the investment requires during 25 years. Net Cash Flow is the Net Income plus the Depreciation Net Present Value (NPV) is the difference between the present value of cash inflows and the present value of cash outflows (eq. (3)). C_0 is the initial investment cost, Ct is the net cash inflow during the period t, N_y is the Life time and i is the

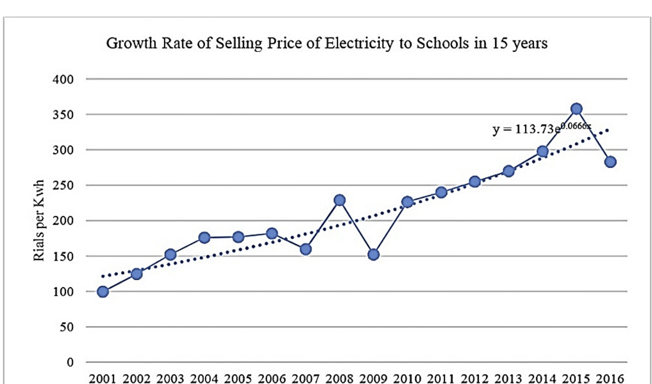

Fig. 9. A yearly increasing of 6.6% in the prices of electricity.

discount rate. NPV is used in capital budgeting to analyze the profitability of a projected investment or project to see if the generated benefits are greater than the costs or not. Thus, the larger and the more positive NPV is, the more economical the investment is.

$$NPV = \sum_{t=1}^{N_Y} \frac{C_t}{(1+i)^t} - C_0 \quad (3)$$

Net Cash Flow and Net Present Value are both negative, Table 3. If schools invest in a 5 kW system, they will averagely lose around 15,100$, but if the government invests in a 5 kW system, they will averagely gain around 27,357$. Results show poor economic performance of PV panels under subsidized average tariffs and why public schools do not invest in these systems. Figs. 10 and 11 clearly explain economic performance of PV panels under both real prices and subsidized prices.

The levelized cost of energy (LCOE) is also calculated to show net present value of generated electricity unit-cost over a twenty years lifetime period of the panels. It is affected by combination of capital costs, operations and maintenance (O & M), performance, and fuel costs. Using the NREL levelized cost of energy calculator, the LCOE is 78.5 cent/kWh which equals to 31.9 cent/kWh in Simple Levelized Cost of Renewable Energy (cents/kWh) (Levelized Cost of Energy Calculator). Results show that electricity generated by solar PVs is more expensive than small hydro and wind electricity in Iran which are 15.4 and 18.26 cents/kWh, respectively (Barimani, 2016).

4. Discussion

According to the results, generated electricity of the PV systems does not have any correlation with schools' energy consumption; the generated energy accounts for 18%–186% of the annual energy consumption of the schools (8569–8949 kWh). This shows that no feasibility study is done for deciding upon power capacity of the

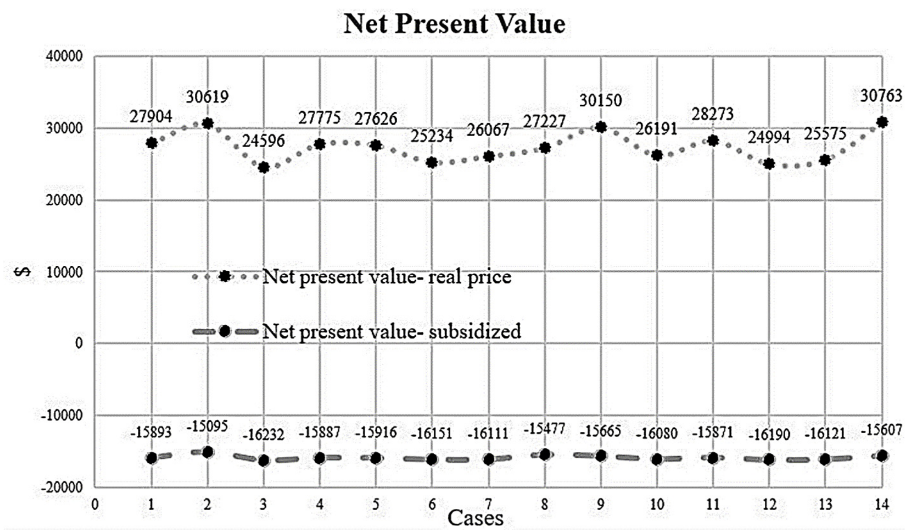

Fig. 10. Net Present Value of PV systems.

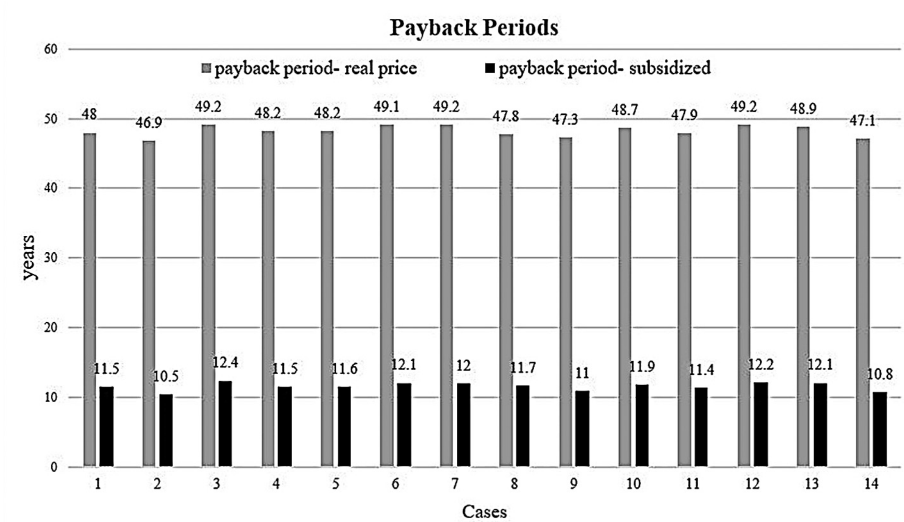

Fig. 11. Payback periods of PV systems.

systems.

Regarding panels' output, lower energy generation of split PV arrays can be described by energy loss in wiring and voltage intolerance due to partial shading. The shading can affect energy efficiencies of the system with the most important effect in case of horizontal shading (Bayrak et al., 2017). However, this effect cannot be shown by all software such as Energy plus. Simulation results could be considered a method of bracketing the upper end of electricity production rather than an accurate prediction of what the panels will produce in a real installation.

Comparing average performance ratio of grid connected PV panels in different countries (Ayompe et al., 2011; Kymakis et al., 2009; Decker and Jahn, 1997; Sidrach-de-Cardona and Mora López, 1999; Drifet al, 2007; Mondol et al., 2006; Pietruszko and Gradzki, 2003; De Miguel et al., 2002; Chokmaviroj et al., 2006) shows that performance ratio of the present study (67.6%) stands in between and is close to the average of these ten cases which is 69% (Fig. 12). This ratio can be increased by designing arrays more efficiently and cleaning tiles. Comparing payback period of PV panels in different countries (Liu et al., 2015; Al-Salaymeh et al., 2010; Quansah and Adaramola, 2016; Bianchini et al., 2016; Fathabadi, 2016a, 2016b; Hammad et al., 2017), shows that apart from solar potentials of each country, many factors including the type of panel, its material, its capacity, inflation rate and country's policies can make a huge difference in payback periods (2.3–60 years), as shown in Fig. 13.

Barriers to adoption of PV technology vary across context (Noorpoor and Kudahi, 2015), as the acceptability does. The policies in different countries are mostly based on financial aspects, such as subsidy policy (governmental consumers and product subsidies), tax policies, especially using polluter-pays system, and monetary policy (such as low-interest loans or export credits), and finally price policies (even fixed or floating price (Shuiying et al., 2011). Germany, China, Japan, Italy (Di Dio et al., 2015) and Portugal (Behrens et al., 2016) are among countries making efforts to switch to renewable energy sources by adopting broad range of policies including feed-in tariffs (FITs), tendering, net metering and fiscal incentives. However, tenders (competitive bidding or auctions) for

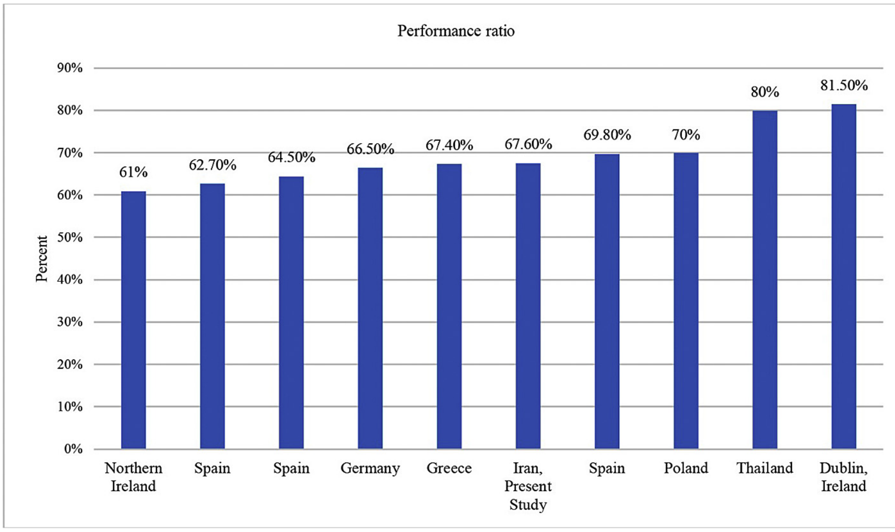

Fig. 12. Shows performance ratio of grid connected PV panels in different countries.

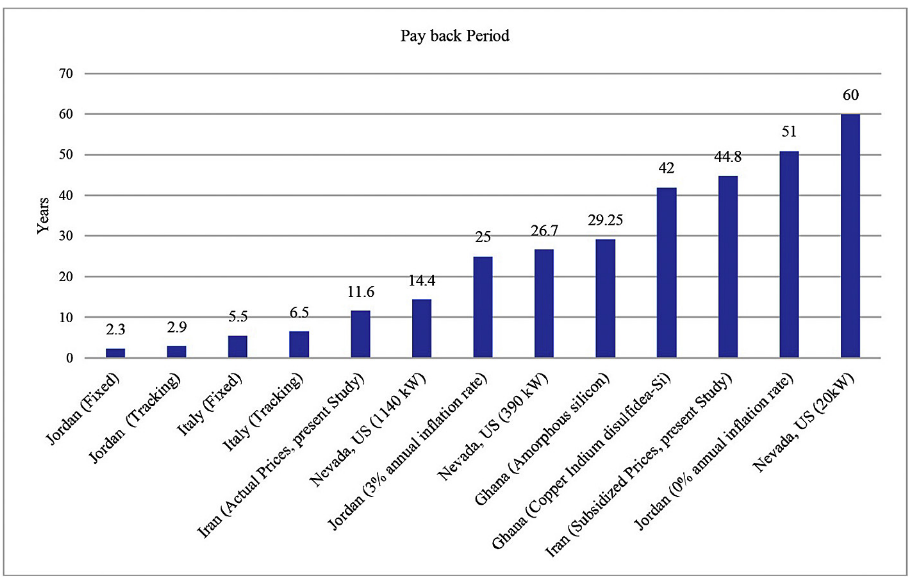

Fig. 13. Shows payback period of different PV panels in different countries.

renewable energy are the most rapidly expanding form of support for renewable energy project deployment and are becoming the preferred policy tool for large-scale projects (Levelized Cost of Energy Calculator). FITs are the most widely utilized form of regulative support to the renewable power sector. According to (Campoccia et al., 2007), FIT for Field Installed PV(FIPV) systems are not convenient in Germany and in France. However, in Spain FIT are very convenient only when the rated PV power is smaller than 100 kWpp (because of the different values of feed-in tariffs). In Italy FIT for FIPV systems are convenient for all the rated installed PV powers. Moreover, FIT for Building Integrated PV Systems (BIPV) systems are convenient for all the EU countries, except in Spain when the installed PV power is over 100 kWpp. In England (StrielkowskiŠ. Dalia and Bilan, 2017), new uses of the traditional electricity market and tariffs has created many promising opportunities for reallocating charges from the existing users who may be poor and vulnerable. In Portugal, the combined historical renewable energy policy and renewable energy developments yielded a clear reduction in emissions, in excess of 7.2 MtCO2eq, an increase in GDP of 1557M€, and a creation of 160 thousand job-years (Behrens et al., 2016). In Italy (Di Dio et al., 2015), during an eight year experience on PV panels, named "Conto Energia", a lot of changes were made in the mechanism to solve the uncertainty due to lack of data i.e., simplified authorization, facilitate the spread of the connection and commercial relationship between the producer and the electricity provider which allow a direct profit to be made from the PV energy production.

Results show a significant difference between economic performance under actual electricity per unit costs without subsidies and economic performance under subsidized average tariffs which can be contributed to the wrong policies adopted for electricity and PV systems. States' financial support plays a key role in development of these systems, since without adopting such policies, the high initial costs of PV panels discourage consumers to replace electricity from fossil fuels with clean electricity. Deployment policies have been established all over the world which resulted in a positive growth in annual installation from 2.67 GW in 2007 to 37.6 GW in 2013 (Jia et al., 2016). The government in Iran has also adopted some supporting policies for the development of PV panels, including revised Feed in Tariffs, National Development Fund (allocating oil and gas revenues to finance renewable energy projects) and the Budget for purchasing Renewable Energy Electricity (Bernal-Agustín and Dufo-López, 2006). However, to make PV panels more economically viable and to make them able compete with conventional electricity resources, following policies are recommended.

- In February 2010, an energy price reform happened in Iran to manage the increasing trend of energy; however, 90% of the revenue from the subsidy removal was allocated to the household cash rebate program (Zahedi, 2010). By removing subsidies, part of the revenue can be allocated to provide low interest loans for purchasing and installing PV panels, subsidizing producers of PV panels and consumers of clean electricity.
- To reach the real prices, subsidies for electricity and fuels should be reduced gradually as supported in (Abbaspour and Hennicke, 2005), since fossil-fuel subsidies prevent the deployment and development of PV panels. By this policy, the huge financial burden on the government for subsidies can also be decreased.
- Another strategy is to exempt tax for consumers and producers of non-fuel electricity.
- Deploying PV panels in commercial sector instead of low energy price educational buildings results in lower payback period and better economic performance.
- As supported in (Zahedi, 2010), serious structural changes should be made to help the private sector play a more decisive role in the economy since the energy market is virtually managed by the public sector. If producing fuel electricity could be run by private sectors, the government could consider taxes on fossil fuel pollution like releasing CO_2.
- Designing PV farms with less vital substructures in Iran's deserts with long sunshine hours seems like a profitable solution to take advantage of the potentials of this country and reduce payback period of these systems. However, the price of energy transfer should be considered in such cases.
- Integrating these panels into buildings can also replace common building elements like shading devices, façade elements and roofing materials, therefore can improve economic feasibility of the projects, as supported in (Zahedi, 2010; Bridle and Kitson, 2014). By considering a separation between PV panels and the wall, the air can cool down the temperature of PV panel and absorb heat away from the PV panels (Baljit et al., 2016), which can increase their energy performance.
- Public acceptance is an important factor that can be achieved by raising public awareness about the benefits of these systems and the disadvantages of fossil fuel electricity. Encouraging polices toward this source of energy include discounts on water and gas bills for consumers of clean energy since solar electricity does not require water, and guaranteeing maintenance and operation costs of these systems.

These strategies should be considered by the government to remove barriers to clean energy and to take advantage of numerous economic and environmental benefits that PV panels offer. For policy makers who are interested in reducing carbon emissions and dependence on fuel-based electricity, the deployment of PV panels may be a very good solution. Investing in PV systems can also create more job opportunities, as confirmed in (Abbaspour and Hennicke, 2005), which in turn leads to better economic situation of the country. Overall, highly subsidized price of energy, centralized ownership of main energy resources in Iran, limited access to international finance, high inflation rates, limited knowledge on technology and installation impede PV panels' development.

For reducing electricity usage and air pollution, energy consumption and energy efficiency in schools should also be closely examined and improved; like considering the efficiency of electrical appliances and insulations. To decrease air pollution, the efficiency of power stations should be increased, technical problems should be removed and electricity transmission losses should be decreased. By this policy, the price of producing 1 kWh electricity also declines, and the gap between the prices paid by consumers and the real prices decreases. It is worth mentioning that applying the experience of successful countries in terms of solar systems and PV panels leads to a faster growth of these systems.

5. Conclusion

Sustainable forms of energy should guarantee both economic feasibility of the investment and efficient electricity generation which are both so crucial in the advent of new technologies. In recent years, economic and environmental features of PV panels have drawn the attention of designers, policy makers, and engineers.

The price of electricity for schools is highly subsidized which is mainly due to the policy of providing cheap education for students. Highly subsidized electricity for schools, environmental concerns and social aspects are among incentives that have encouraged the government to install these panels on the roof of public schools. Considering the real price of fuels, 1 kW h electricity costs 0.21$ in Iran, approximately 25 times higher than what schools pay averagely for, 0.011$. The results of this study show that the economic performance of PV panels does not encourage consumers of fossil fuel electricity to install these systems. However, these systems are quite economically viable for the state. Results show a significant difference between economic performance under actual electricity per unit costs without subsidies, PBP ranging from 10.5 to 12.3 years, and economic performance under subsidized average tariffs, PBP ranging from 46.9 to 50.5 years. Under subsidized prices, NCF and NPV are both negative and the cash generated by investment cannot even offset the costs that the investment requires during 25 years. Accordingly, the study discusses the policies that can make PV panels more economically viable. Further studies are required to investigate economic performance of PV panels in Housing, Industrial sector and in Universities.

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